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On the Role of Friction when Welding with Ultrasound

(O ROLI TRENIYA PRI SVARKE UL'TRAZVUKOM)

by

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The process of welding metals by ultrasound has not been yet sufficiently investigated and the mechanism of the formation of joints is explained in various methods. ~~xxxxx~~ In the investigation by [1,2] ultrasonic welding is separated into an independent form of joining metals, it is not analogous to the known welding methods, but noticed is the positive role of heating the details in process of welding on account of friction. The relative displacement of details and the plastic flow of the metal in the zone of welding are considered by the authors as the basic cause of disruption in the continuity of surface layers and elimination of same. According to author [3] the main factors instrumental in the formation of joints are the higher~~xx~~ energy levels of the atoms of the crystal lattice of the metal near the welded surfaces, activation of diffusion processes in ultrasonic flied and origination of considerable shearing stresses in the micro-contacts.Combined action of these factors cause the formation of common crystals on the boundary of details. In the investigation [4,5] we find an analogy of the gripping (setting) processes during ultrasonic welding and dry friction. However, this condition is also confirmed by calculation and experimentally but only for the contact between the tip of the ultrasonic tool and the plate. In the experiment [6] ultrasonic welding is considered as a partial case of welding under pressure

at higher temperature. The effect of ultrsonic oscillations is used for the elimination of surface films and heating the contact to a temperature at which the resistance to deformation of details is reduced by several times. A study of the process of joint formation during ultrasonic welding, carried out at the Institute of Metallurgy of the Academy of Sciences USSR shows, that one of the important phenomena occurring during the welding, should be considered the heating of details at point of contact. Presented below are certain data regarding the study of temperature field distribution in welded details during the process of ultrasonic welding.

Fig.1 shows the change in temperature with time (curve 1) at the point of contact of the ultrasonic welded details. Welded were Chromel and Alumel plates with a thickness of 0.1 mm. The temperature was fixed by the POB-12 oscillograph which recorded the thermoelectric current formed by the pair of Chromel -Alumel plates. To exclude EMF shunting the plates were welded over a Teflon layer.

Fig.1.Change in temperature (1) in contact between details and strength of joints (2) in relation to the time of welding.

On fig.1. is also given the dependence of joint strength (curve 2) upon time of welding. The methodical curve 2 was plotted on basis of data obtained during shearing tests of joints obtained within various time periods. Comparing both curves (Fig.1) one will notice two characteristic traits in the process of joint formation. The first one consists in the fact that the temperature maximum coincides with the moment of welding,whence the strength of the joint

43 remains practically constant; the second one lies in the fact that zero strength does not coincide in time with the outset of temperature rise.

This and the other one can be explained, if we were to assume, that the source of heat during ultrasonic welding is friction, which develops between the compressed details during application of elastic oscillations tangentially to the upper surface of same. It is apparent, that the shift of tool tip cause displacement of the upper detail with respect to the lower one. As result on account of friction the details begin warming up at the point of their contact. It is also apparent that the heating will continue until the source of heat will become effective, i.e. until relative displacement of the detail will take place. The temperature maximum in this case should correspond to the moment of discontinuation of the relative displacement of the details. However, keeping in mind the curve representing the change in the strength of the joint, it should be assumed, that during the heating of the details at the point of contact develops the process of partial thermal setting at which, apparently, there is subsequent formation and destruction of the joint.

At the beginning of the welding process on account of the displacement of the upper detail relative to the lower one, at the point of their contact should take place the disruption of surface layers (oxides, special coatings etc.) With this, apparently, is necessary to explain the mentioned discrepancy between the beginning of joint strength growth and the beginning of temperature rise. As time passes on, i.e. as the temperature rises the area of

Fig. 2. Curves showing change in temperature at tip-detail contacts (1) and detail-detail contact (2).

the contact will grow (just as during the heating there is an increase in the plastic properties of the metal in contact) and, consequently, there should also be an increase in the strength of the joint. At a definite strength, i.e.at a definite moment of joint development the relative displacement of details discontinues and to this moment of time corresponds atemperature maximum in the joint. This time interval should be considered, apparently, as the minimum welding time.

Highly important in the process of ultrasonic welding are the conditions of transmitting displacements of the tool of upper detail through the tip. It is evident that the transmission of displacements is possible either on account of tool tip and upper detail friction alone or as result of formation between them of a sufficiently strong joint. In fig. 2 are given curves showing the change in temperature at tool tip upper detal contact points (curve 1) and contact points of details (curve 2). These curves are analogous to each other but the temperature maximum in the tool tim/upper detail contact point is attained somewhat sooner than in contact between the details. If, in conformity with aforementioned, we were to assume that the maximum on the temperature change curve is the result of formation of a strong joint (discontinuations of relative displacement of contacting elements)then it can be considered that also between the tool tip and upper detail is formed a joint the strength of which is sufficient for transmission of displacements at the point of contact of the welded together details. The jointing of the tip with the upper detail is formed sooner than the jointing between details. However the nature of the tip/upper detail joint should be principally different than the nature of the joint between the details, because the joint between the details is formed

44 thanks to the development of setting processes in plastic contact, and between tip and detail- in the contact of the plastic material of the detail with the solid material of the tip. This, apparently , would explain the relatively easy separation of the tip from the upper detail and the formation of a strong joint between the details.

Fig.3. Microstructure of joint obtained by ultrasonic welding of two copper strips with a thickness of 0.5 mm (X 40)

Fig.3, shows a ~~photo~~ microphoto of a joint between two copper strips, which prior to welding were annealed at 650°. On the photo is clearly visible the zone of the ~~mat~~ material of upper and lower details, subjected to intensive plastic deformation at combined action of ultra sound and normal stress. Attention is called to the fact that the plastic flow of the material during the welding enveloped the upper and lower details only in the narrow layer at the boundary of their contact.

Fig.4. Curves for temperature distribution in upper and lower details during ultrasonic welding (a) and arrangement of thermocouples (b) 1-0.02 sec; 2-0.03 sec

Fig.4. continued

3- 0.065 sec; 4- 0.13 sec; 5- 1.0 sec. a- steel 45; b- constantan; c- teflon; d-iron.

To explain the causes of such a phenomenon experiments were conducted to study temperature distribution in the body of lower and upper details because the plastic flow in the plate contact under the effect of a small contact force is possible only when the material is heated to a specific temperature. On fig. 4 are shown graphs oftemperature distribution along the thickness of upper and lower details as well as temperature distribution curves along the width of the lower plate at a depth of 0.6 mm from its surface. The temperature in the body of the plate was measured with artificial Chromel-Kopel thermocouples with a diameter of 0.2 mm. The upper plate - constantan, the lower one - Armco iron. The temperature between the details and between tip and upper detail was measured with natural couples the hot junctions of which were formed in the welding process. The temperature in the center of upper plate was measured with a single wire thermocouple. First of all it is necessary to notice the greater temperature gradient in plates at the surface of their contact. Apparently, the width of the zone, in which plastic deformations do develop, should be equal to the width of the section of details, in which the temperature is not lower than that necessary for plastic flow of material under given conditions of welding. The temperature in the center of the body of the upper plate even toward the end of the welding process does not exceed 200 - 250°.

The nature of temperature distribution over the width of the lower plate indicates the presence of a third source of heat. It is apparent, that this source of heat is distributed over a circle which approximately envelopes the periphery of the contact at the point of jointing (approximate disposition of source

can be determined by the nature of the maximum on the temperature distribution curve).

The reason for the formation of an annular source can be as follows: the tip moving tangentially to the surface of the upper detail, first on account of friction, and then on account of formation of joints between them draws into movement a part of the material of the upper plate. This movement should, apparently, bear the very same nature of displacement varying in direction as the movement of the tool tip. Evidently, in intensive movement should be that part of the material which is situated directly under the tip. For this reason on the boundary of the mentioned zone of the upper detail originate sign changing tangential shearing stresses and elongation and compression stresses, which can be the cause for the origination of heat on the contact periphery between the tip and upper detail. It is also apparent, that the intensity of this peripheral heat source should rise with time and reach maximum value at the moment of formation of a sufficiently strong joint between tip and upper detail. For this very reason during the welding of materials with low heat conduction is observed the appearance of rings of temper color aroundthe welded point on the upper detail.

The temperature curves with sharply expressed maximum can be found, as a rule, in case of weldingat a frequency close to resonance and at low capacity of ultrasonic oscillations. In this case a change in Eigen-Frequency of oscillations of the welding head because of the tip becoming welded on to the detail, sharply reduces the amplitude. With the increase in acoustic power the oscillatory system becomes less sensitive to the setting of the tip with the details. Furthermore, a greater supplied acoustic power makes more probable the destruction of sections of the joint, formed between tool andupper detail, which frees the tool from the joined mass.

Consequently the welding at greater capacitances is characterized by greater stable process of ultrasonic oscillations and, consequently, also by strength of joint.

A change in interaction between tip and detail is reflected on the nature
of temperature change. In case of tip slipping relative to the detail the tem
perature rises uninterruptedly up to the moment of thermal saturation. The
surface of the point in this case is shiny,and the strength of the joint- very
low. The latter thing is ordinarily observed at small values of the contact for
ce and greater amplitudes of ultrasonic oscillations. As the contact force in-
46 creases the likelihood of tip slipping decreases, the energy of ultrasonic oscil
lations becomes localized preferably between the details and the joint becomes
much stronger [7].

The interaction processes between tip and detail can be controlled not only by the parameters of the process, but also by the selection of working tool material and treatment of its surface.

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